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Investigating the Disappearance of Short-finned Pilot Whales (*Globicephala macrorhynchus*) from Southern California: Did Fisheries Play a Role?

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Abstract.—There is a mystery surrounding the disappearance of short-finned pilot whales (*Globicephala macrorhynchus*) from southern California. This species was very common in these waters through the early 1980s, with an apparently seasonally-resident population centered around Santa Catalina Island in the Southern California Bight. From 1980-1985, pilot whale numbers off Catalina Island declined dramatically, and they eventually disappeared. One theory has been proposed for this phenomenon, suggesting that a strong El Niño event in 1982/83 resulted in a failure of their main prey, market squid (*Doryteuthis opalescens*), which lead to their departure. However, we argue that previously underestimated impacts from fishery by-catch and other anthropogenic effects may have actually been the primary driver. Information from diverse sources show that from the 1950s to 1980s, pilot whales were subject to extensive by-catches in purse-seine nets, lampara nets, and oceanic driftnets, as well as intentional shooting by fishermen, and live-captures for the aquarium industry. As a result, dozens of animals may have been removed in some years. From 1952 to 2014, we have documented no less than 232 individuals removed from southern California, with >52% through known anthropogenic factors. If these removals primarily affected the Catalina Island 'residents', they would have had a severe impact on that population. We conclude that human interactions of various types almost certainly played an important, and previously unrecognized, role in the disappearance of short-finned pilot whales from southern California waters.

One of the great mysteries in American marine mammal biology has to do with the short-finned pilot whale (*Globicephala macrorhynchus*) population or populations in southern California. This species has been known from the southern California and Baja California coasts for over a century, and in 1920 Nidever (1921) reported a school of about 100 near Santa Catalina Island (hereafter referred to as "Catalina Island"). The species was common in southern California waters through the mid-1980s, and a "resident population" was thought to occur around Catalina Island in the southern California Bight (SCB) (Leatherwood et al. 1973; Walker 1975; Dohl et al. 1981). Around 1983/1984, a dramatic decline in their numbers was evident, and they essentially disappeared from California waters. Since that time, short-finned pilot whale sightings have been infrequent and broadly distributed along the coast, rather than concentrated near Catalina Island (Barlow and Forney 2007; Kendall-Bar 2015; Kendall-Bar et al. 2016). In the space of a few short years,

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Fig. 1. Short-finned pilot whales observed off Palos Verdes, California, in December 1986, showing distinctive features used in photo-identification. Photo by A. Schulman-Janiger.

they went from being one of the most common cetacean species in southern California to being essentially absent.

Focal studies of the species documented this disappearance (Shane 1995a), but only one explanation has been offered for this unprecedented event. The hypothesis was advanced that the pilot whales moved away in response to the 1982/83 El Niño, which disrupted the annual squid (*Doryteuthis opalescens*) spawning around the Channel Islands, on which the pilot whales apparently depended for food. According to this theory, an influx of Risso's dolphins (*Grampus griseus*) then moved into the area and occupied the pilot whales' teuthophageous niche, thereby inhibiting the pilot whales from returning (Shane 1991; 1995a,b). Several points have been offered in support of this hypothesis (see discussion below), but there are other alternative explanations that have not been fully considered.

The El Niño theory was never proven and it was never determined where the pilot whales may have gone (Fig. 1). Despite the increase in surveys along the U.S. West Coast and the coast of Baja California, Mexico (Barlow and Forney 2007; Wade and Gerrodette 1993, Ferguson and Barlow 2003; Hamilton et al. 2009), no areas with pilot whale concentrations of a similar magnitude have been documented. Besides the above-mentioned El Niño and associated effects, there were a number of other changes and activities happening in southern California at the time that the pilot whales disappeared. Our goal in this paper is to re-examine this issue, and to consider the potential role that fisheries interactions may have had in the pilot whales' vanishing. We will proceed by reviewing published and unpublished information (supplemented with new data and analyses) on several aspects of the biology of these animals in southern California.

Materials and Methods

Pilot whale stock structure information for southern California and also for the entire eastern North Pacific was examined through review of both published and unpublished

Table 1. Strip transect estmates of density and abundance of short-finned pilot whales within 15 km of Santa Catalina Island (data from Oliver and Jackson 1987). D = individual density, N = abundance.

Time period	Years	Agency*	Surveys	Effort (nm^2)	Groups sighted	D (#/nm^2)	N	CV
1	1980/81	CDFG	15	1,575	167	0.9744	300	0.50
2	1982/83	NMFS	9	1,049	43	0.4004	123	0.23
3	1983/84	NMFS	6	850	0	0	0	n/a
4	1984/85	NMFS	5	710	2	0.0887	27	2.95
5	Late 1985	NMFS	2	242	1	0.0372	11	n/a

* CDFG = California Department of Fish and Game; NMFS = National Marine Fisheries Service.

literature. Distribution of short-finned pilot whales in the SCB was evaluated by creating a database of sightings from historical studies off southern California. To be included, these studies must have conducted systematic searches for cetaceans or compiled pilot whale sightings and have presented either specific positions for the sightings in the form of latitude/longitude coordinates or provided maps of the sightings for which positions could be estimated. Sources of such literature included Fiscus and Niggol (1965) and Norris and Prescott (1961) for the 1950s and early 1960s, Leatherwood et al. (1973), Dohl et al. (1981), and Bonnell and Ford (2001) for the 1970s and early 1980s, Oliver and Jackson (1987) for the 1980s, and multiple cruise reports for surveys conducted by the U.S. National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC) of the U.S. West Coast between 1991 and 2014.

In addition to reviewing available estimates of abundance from the literature, we also used an existing, but unanalyzed, dataset to calculate a new historical estimate of density and abundance for the area around Catalina Island. Strip-transect surveys targeting short-finned pilot whales around Catalina Island were conducted by the California Department of Fish and Game (CDFG), and later by the SWFSC between 1980 and 1985 (Oliver and Jackson 1987). Surveys were conducted from December through March (thus 1981/82 refers to the period of December 1981-March 1982). The surveys used a Cessna 337 Skymaster fixed-wing aircraft, and were flown at an altitude of 500 feet at ground speeds of 90-100 knots. Two observers in rear seats monitored a strip 0.5 nm wide, while the pilot and data recorder occupied the front seats of the aircraft (Oliver and Jackson 1987). We did not have access to the raw data, but we used processed data that were presented in an administrative report (Oliver and Jackson 1987). These data were not previously analyzed to obtain density or abundance estimates. Although there were some inconsistencies in the study areas and survey procedures over the study period, it was possible to obtain approximate estimates of abundance for pilot whales for the study area of 308 nm^2 around Catalina Island, by using strip transect methods. Total numbers of sightings and survey effort for each survey period are shown in Table 1. Density, abundance, and their associated coefficient of variation were calculated as:

$$D = \frac{n\,E(s)}{wL}$$

$$N = D\,A$$

$$CV = \frac{var\,(n/L)}{(n/L)^2} + \frac{var\,[E\,(s)]}{E(s)^2}$$

where D = density (of individuals),

N = abundance,
n = number of sightings made on effort,
E(s) = average group size,
w = width of the survey strip,
L = length of transect completed,
A = size of the study area,
var = variance, and
CV = coefficient of variation.

In order to evaluate and estimate total annual mortality/removals from the SCB, we compiled an Excel table of all known by-catch records, live-captures, and strandings of short-finned pilot whales in California. Stranded specimens that were determined to have died from by-catch after examination were listed as by-catch in the table. "Removal" is here defined as any mortality (natural or anthropogenic), or any physical removal of animals from the population (such as through live-captures). Data came from the published and unpublished literature, as well as records of the Los Angeles County Museum of Natural History (LACM - courtesy of D. Janiger) and the U.S. Navy (courtesy of S. H. Ridgway). As the live-captures were conducted as part of an organized fishery to supply aquaria and research institutes with live cetacean specimens, we consider these removals to be a type of fishery interaction separate from by-catch. We scrutinized and error-checked the database and attempted to eliminate possible duplicate records (see Table 2).

Results and Discussion

The historical stock structure of short-finned pilot whales off California is not well understood; it is currently considered by NMFS that there is a single stock off California/Oregon/Washington (Carretta et al. 2017a). There is an apparent hiatus in distribution centered at around 20°N, which is interpreted to provide evidence that the large number of animals in the Eastern Tropical Pacific (ETP) are from separate populations (Reilly 1977). Multiple stocks are hypothesized to occur in the ETP, but by virtually all accounts, the animals in southern California (and presumably north) were part of a different stock (Reilly 1977; Polisini 1980). This is the so-called "Californian" population center of Reilly (1977) and Polisini (1980). More recent information from Hamilton et al. (2009) suggested that hiatuses in distribution occur at about 18°N and 30°N, providing further support that California animals may be distinct from those in the ETP, and even off southern Baja California, Mexico. However, Forney (1994) questioned whether animals off California were a discrete stock from those in Baja. A recent photo-identification effort revealed that there were several matches from whales off San Clemente Island in 2007 to whales off northern California (offshore of Monterey Bay) in 2008, and to whales in Baja California in 2011; there was also one match between San Clemente Island and northern Baja California in 2015, which suggests that there might actually be a fluid population extending from Baja California northward (Kendall-Bar 2015; Kendall-Bar et al. 2016). Molecular techniques have only recently been applied to the issue of population variation in Pacific pilot whales. Although Van Cise et al. (2016) did not find evidence of strong differentiation in mtDNA control region sequences between California Current and ETP samples, sampling was limited and quite sparse in many cases, and this study therefore does not discount smaller-scale population division.

Although not confirmed through detailed long-term studies, there was a general consensus in the 1970s/80s that there was a resident population (or subpopulation) of pilot whales

Table 2. Documented mortality/removals of short-finned pilot whales in the southern California Bight, 1950-present.

Event #	Date	# Animals	Record type	Location/notes	Reference(s)
1	26-Jul-52	2	Stranding	Imperial Beach (San Diego Cty) - 521 cm M	Danil et al. 2010
2	20-Aug-52	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010, LACM unpubl.
3	23-Jan-54	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
4	9-Feb-56	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
5	6-Feb-57	1	Stranding?	Live capture at Catalina Island - 290 cm M	Norris and Prescott 1961
6	27-Feb-57	1	Capture (live)	Live capture for Marineland ("Bubbles") - young adult 396 cm F	Brown 1960; Norris and Prescott 1961, LACM unpubl.
7	19-Jun-57	1	Capture (live)	Live capture for Marineland ("Squirt")	Gilmore 1962
8	26-Nov-57	1	Stranding	Subadult at Huntington Beach	Norris and Prescott 1961
9	12-Jun-58	1	Stranding	18′3″ male at Torrance Beach	Norris and Prescott 1961
10	21-Jan-59	2	Capture (live)	Live capture for Marineland ("Bimbo") - 524 cm M	Norris and Prescott 1961; Gilmore 1962
11	3-Feb-59	1	Stranding?	San Pedro - 368 cm M	Norris and Prescott 1961
12	8-Feb-59	1	Capture (live)	Live capture - 287 cm M	Norris and Prescott 1961
13	2-Mar-59	2	Capture (live)	Live captured and released - 208 cm F and 275 cm M	Norris and Prescott 1961
14	25-May-59	12	Stranding	Unknown/San Miguel Island	Norris and Prescott 1961
15	25-Jun-59	1	Stranding	Adult at Belmont Shores Beach	Norris and Prescott 1961
16	28-Jan-60	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
17	31-May-60	1	Capture (live)	Live capture S of Pt. Vicente - 263 cm F	Norris and Prescott 1961
18	7-Sep-60	2	Stranding?	San Miguel Island	LACM unpubl.
19	1960	3	Capture (live)	Live captures for Marineland	Gilmore 1962
20	20-Jan-61	1	Stranding?	Long Beach - 381 cm M	LACM unpubl.
21	14-Jun-61	1	Stranding?	Catalina Island	LACM unpubl.
22	9-Mar-62	15	Stranding	San Clemente Island	Mitchell 1965
23	27-Nov-62	1	Capture	San Clemente Island	Rice 1963
24	15-Mar-63	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
25	31-Mar-63	3	Stranding	San Clemente Island	LACM unpubl.
26	28-Aug-63	1	Stranding?	Marineland - 343 cm F	LACM unpubl.
27	15-Mar-65	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
28	31-Aug-66	1	Capture (live)	Live capture for Marineland - 287 cm M	Walker 1975
29	6-Sep-66	1	Capture (live)	Live capture for Marineland - 358 cm F	Walker 1975
30	7-Sep-66	1	Capture (live)	Live capture for Marineland - 320 cm F	Walker 1975, LACM unpubl.

Table 2. Continued.

Event #	Date	# Animals	Record type	Location/notes	Reference(s)
31	18-Sep-66	1	By-catch	By-catch - 197 cm F	LACM unpubl.
32	21-Nov-66	1	Capture (live)	Live capture for Marineland - 340 cm F	Walker 1975
33	23-Nov-66	1	Capture (live)	Live capture for Marineland - 292 cm F	Walker 1975
34	28-Mar-67	1	Capture (live)	Live capture for Marineland - 366 cm F	Walker 1975
35	10-Apr-67	1	Capture (live)	Live capture for Marineland - 292 cm F	LACM unpubl.
36	20-Apr-67	2	Capture (live)	Live captures for Marineland	LACM unpubl.
37	15-Jun-67	1	??	Catalina Channel - 330 cm F	LACM unpubl.
38	27-Jun-67	1	Capture (live)	Live capture for Marineland - 246 cm F	Walker 1975
39	28-Jun-67	1	Capture (live)	Live capture for Marineland - 480 cm F	Walker 1975
40	23-Aug-67	1	Stranding	Unknown	Danil et al. 2010
41	4-Mar-68	1	Capture (live)	Live capture for Marineland - 381 cm F	Walker 1975
42	11-Mar-68	1	Capture (live)	Live capture for Marineland - 320 cm F	Walker 1975
43	?? Oct 68	1	Capture (live)	Live capture for US Navy ("Morgan") - 12′ M	Bowers and Henderson 1972
44	6-May-69	1	Capture (live)	Live capture for Marineland - 290 cm M	Walker 1975, LACM unpubl.
45	9-May-69	1	Capture (live)	Live capture for Marineland - 259 cm F	Walker 1975
46	21-May-69	1	Capture (live)	Live capture for Marineland - 277 cm M	Walker 1975
47	29-May-69	1	Capture (live)	Live capture for Marineland - F	Walker 1975
48	2-Jun-69	1	Capture (live)	Live capture for Marineland - 325 cm M	Walker 1975
49	?? Jul 69	1	Capture (live)	Live capture for US Navy ("Modo")	S. H. Ridgway, pers. comm.
50	17-Sep-69	1	Capture (live)	Live capture for Marineland - 373 cm M	Walker 1975
51	8-Oct-69	1	Capture (live)	Live capture for Marineland - 457 cm F	Walker 1975, LACM unpubl.
52	31-Oct-69	1	??	Santa Barbara - 295 cm M	LACM unpubl.
53	10-Dec-69	1	Stranding/by-catch	Fishery interaction	Hacker 1986; Sinclair 1992
54	26-Dec-69	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
55	??	8-10	Capture (live)	Captured for Sea World, with some mortality	S. H. Ridgway, pers. comm.
56	7-Jan-70	1	Capture (live)	Live capture for Marineland - 310 cm F	Walker 1975
57	18-Jan-70	1	Capture (live)	Live capture for Marineland - 348 cm M (or 310 cm)	Walker 1975, LACM unpubl.
58	22-Jan-70	1	Capture (live)	Live capture for Marineland - 320 cm M	Walker 1975, LACM unpubl.

Table 2. Continued.

Event #	Date	# Animals	Record type	Location/notes	Reference(s)
59	23-Jan-70	1	Capture (live)	Live capture for Marineland - 325 cm M	Walker 1975, LACM unpubl.
60	29-Jan-70	1	Capture (live)	Live capture for Marineland - M	Walker 1975
61	?? Jan 70	1	Capture (live)	Live capture for US Navy ("Pip") - 366 cm M	Bowers and Henderson 1972
62	6-Feb-70	1	Capture (live)	Live capture for Marineland - 320 cm F	Walker 1975, LACM unpubl.
63	3-Nov-70	1	Capture (live)	Live capture for Marineland - 396 cm F	Walker 1975, LACM unpubl.
64	11-Dec-70	1	Capture (live)	Live capture for Marineland - 305 cm M	Walker 1975
65	8-Jan-71	28	Stranding	San Clemente Island mass stranding - 6 M, 21 F, 1 ?	Hall et al. 1971, LACM unpubl.
66	10-Nov-71	1	Capture (live)	Live capture for Marineland - 315 cm F	Walker 1975
67	11-Nov-71	1	Capture (live)	Live capture for Marineland - 326 cm F	Walker 1975
68	2-Feb-72	1	Capture (live)	Live capture for Marineland - 330 cm F	Walker 1975
69	24-Mar-72	1	Stranding?	San Clemente Island	LACM unpubl.
70	21-Nov-72	1	Capture (live)	Live capture for Marineland - 320 cm F	Walker 1975, LACM unpubl.
71	30-Nov-72	1	Capture (live)	Live capture for Marineland - 305 cm F	Walker 1975
72	1-Dec-72	1	Capture (live)	Live capture for Marineland - 351 cm F	Walker 1975; LACM unpubl.
73	12-Dec-72	1	Capture (live)	Live capture for Marineland - M	Walker 1975
74	15-Dec-72	1	Capture (live)	Live capture for Marineland - F	Walker 1975; LACM unpubl.
75	12-Mar-73	1	Stranding	Solan Beach (San Diego Cty) - 453 cm F	Danil et al. 2010; LACM unpubl.
76	15-Mar-73	2	Stranding	La Jolla (San Diego Cty) - 437 cm F	Danil et al. 2010
77	24-Mar-73	1	Stranding	San Clemente Island	LACM unpubl.
78	3-Apr-73	1	Stranding	Camp Pendelton - 434 cm F	LACM unpubl.
79	12-Apr-73	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
80	24-Jul-73	1	Capture (live)	Live capture, San Pedro Channel - 351 cm F	
81	27-May-05	3	Capture (live)	Live-capture	Reeves and Leatherwood 1984
82	15-Oct-75	1	Stranding/by-catch	Fishery interaction (from forensic evidence) - Palos Verdes - 461 cm F	Heyning et al. 1994; Sinclair 1992; Hacker 1986
83	7-Nov-75	1	Stranding/by-catch	Fishery interaction (from forensic evidence)	Heyning et al. 1994; Sinclair 1992; Hacker 1986

Table 2. Continued.

Event #	Date	# Animals	Record type	Location/notes	Reference(s)
84	28-May-05	4	Capture (live)	Live-capture	Reeves and Leatherwood 1984
85	5-Oct-76	1	Stranding	Stranded alive - 249 cm	LACM unpubl.
86	8-Oct-76	1	Stranding	Stranded alive	Otten 1979
87	29-May-05	3	Capture (live)	Live-capture	Reeves and Leatherwood 1984
88	7-Nov-77	1	By-catch	Fishery interaction (caught in anchovy net), LA Cty. - 670 cm M	Heyning et al. 1994; Seagars and Henderson 1985; LACM unpubl.
89	19-Nov-77	2	Stranding/by-catch	Fishery interaction (from forensic evidence), LA Cty. - 419 cm F, 433 cm ?	Heyning et al. 1994; Seagars and Henderson 1985; LACM unpubl.
	22-Nov-77	1	Stranding/by-catch	Fishery interaction (from forensic evidence), Ventura Co. - 422 cm (or 419 cm)	Heyning et al. 1994; Seagars and Henderson 1985; LACM unpubl.
90	23-Nov-77	1	Stranding/by-catch	Fishery interaction (from forensic evidence), Ventura Co. - ca. 430 cm	Heyning et al. 1994; Seagars and Henderson 1985; Hacker 1986
91	16-25 Nov-77	4	Stranding/by-catch	Evidence of fishery interaction and squid in stomachs of some animals	Payne 1978
92	5-Mar-78	1	Stranding?	Manhattan Beach - 447 cm F	LACM unpubl.
93	31-May-05	2	Capture (live)	Live-capture	Reeves and Leatherwood 1984
94	22-Jan-80	1	Stranding/by-catch	Fishery interaction (from forensic evidence), Catalina Island - ca. 500 cm	Heyning et al. 1994
95	2-Nov-80	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
96	5-Dec-80	1	Stranding	Cabrillo Beach	LACM unpubl.
97	17-Dec-80	5	Stranding/by-catch	Fishery interaction, Catalina Island (from forensic evidence)	Heyning et al. 1994
98	19-Dec-80	1	Stranding/by-catch	Fishery interaction (from forensic evidence), Catalina Island - 463 cm F	Heyning et al. 1994, Perrin and Kashiwada 1989
99	1980	12*	By-catch	Entanglement in squid purse seine fishery, Catalina Island	Miller et al. 1983

Table 2. Continued.

Event #	Date	# Animals	Record type	Location/notes	Reference(s)
100	2-Jun-05	3	Capture (live)	Live-capture	Reeves and Leatherwood 1984
101	16/17-Dec-80	6	Stranding	Santa Catalina Island	Seagars and Henderson 1985
102	4-Jun-05	2	Capture (live)	Live-capture	Reeves and Leatherwood 1984
103	1980-83	2	By-catch	Entanglement in CA/OR shark/swordfish driftnet fishery	Hanan et al. 1993
104	29-Jan-83	1	Stranding	San Pedro - 584 cm M	LACM unpubl.
105	12-Feb-85	1	Stranding	Found dead on Catalina Island - 472 cm adult F	Shane FN1
106	??-Jul-85	1	Stranding	Unknown (San Diego Cty)	Danil et al. 2010
107	20-Dec-87	1	Stranding	LA Harbor - 192 cm M	LACM unpubl.
108	3-Jan-88	1	Stranding/by-catch	Fishery interaction (from forensic evidence)	Heyning et al. 1994
109	24-Mar-88	1	Stranding	San Clemente Island - ca. 240 cm	Heyning et al. 1994, LACM unpubl.
110	16-Sep-90	1	Stranding	Silver Strand (San Diego Cty) - 400+ cm	Danil et al. 2010; LACM unpubl.
111	28-Sep-90	1	By-catch	Entanglement in California swordfish/shark driftnet fishery	Julian and Beeson 1998; Hanan 1993; Carretta et al. 2017b
112	28-Aug-92	1	By-catch	Entanglement in California swordfish/shark driftnet fishery	Julian and Beeson 1998; Carretta et al. 2017b
113	Aug-Oct 93	8	By-catch	Entanglement in California swordfish/shark driftnet fishery	Julian and Beeson 1998; Carretta et al. 2017b
114	24-Jun-94	1	Stranding	LA Harbor - 224 cm M	LACM unpubl.
115	9-Sep-97	1^	By-catch	Entanglement in California swordfish/shark driftnet fishery	Barlow and Cameron 2003; Carretta et al. 2017b
116	3-Oct-03	1#	By-catch	Entanglement in California swordfish/shark driftnet fishery	Carretta et al. 2017b
117	25-May-08	1	Stranding	Imperial Beach (San Diego Cty) - ca. 330 cm M	Danil et al. 2010, LACM unpubl.
118	Jan-14	2	By-catch	2 taken in CA swordfish driftnet fishery	Carretta et al. 2017b

* Miller et al. (1983) estimated that the true mortality could be three times as many (i.e., 36 animals).
^ Estimated mortality = 7 (Carretta et al. 2005).
# Estimated mortality = 5 (Carretta and Chivers 2004).

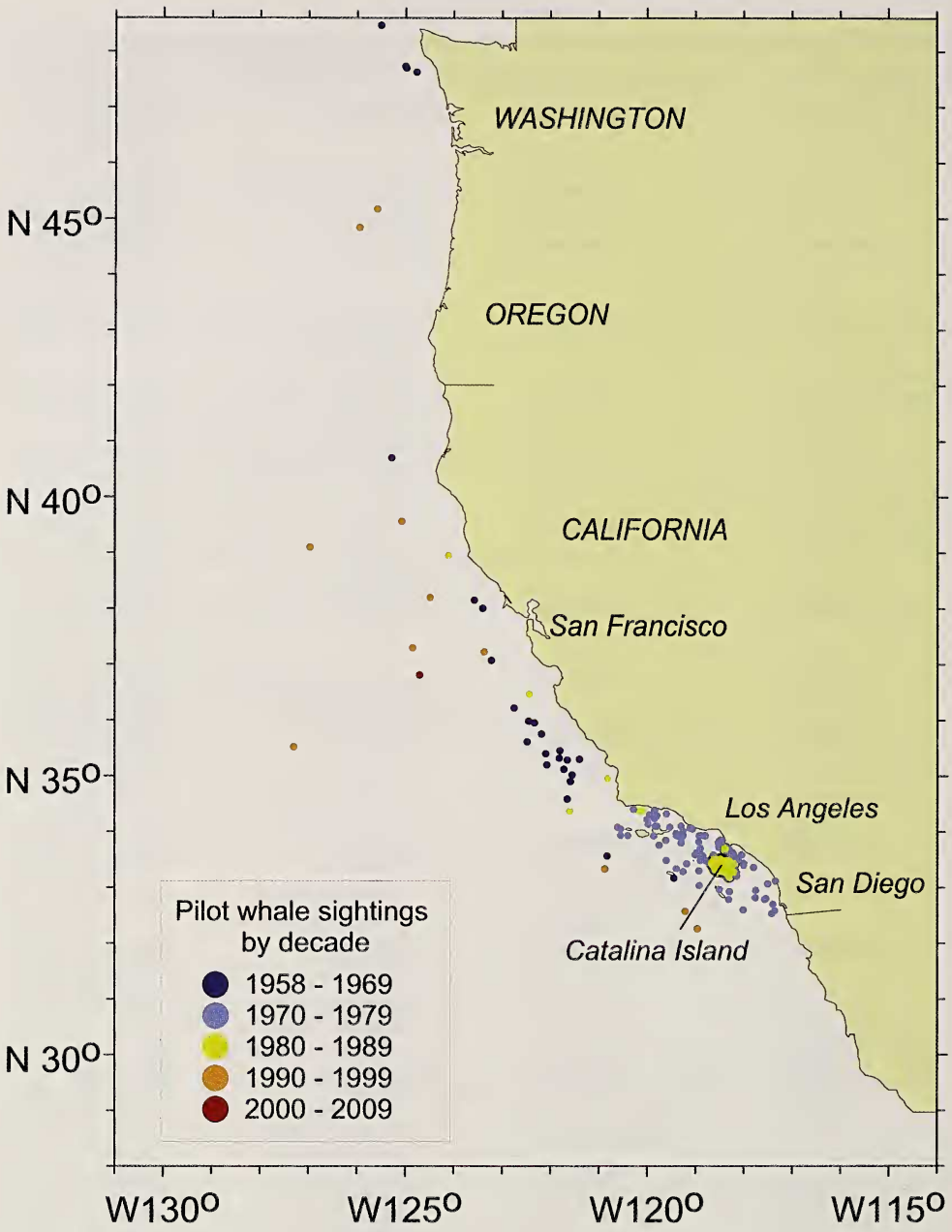

Fig. 2. Map of pilot whale sightings off the U.S. west coast, by decade.

that inhabited the area of the Channel Islands/SCB (including at least Coronado, Catalina, San Clemente, Santa Cruz, Anacapa, and Santa Barbara Islands, the Palos Verdes Peninsula, Pt. Vicente, and Huntington Beach (Leatherwood et al. 1973; Walker 1975; Dohl et al. 1981). The study area, indicating the names of places mentioned, is shown in Figs. 2 and 3. Animals presumably from this population were regularly observed around Catalina Is-

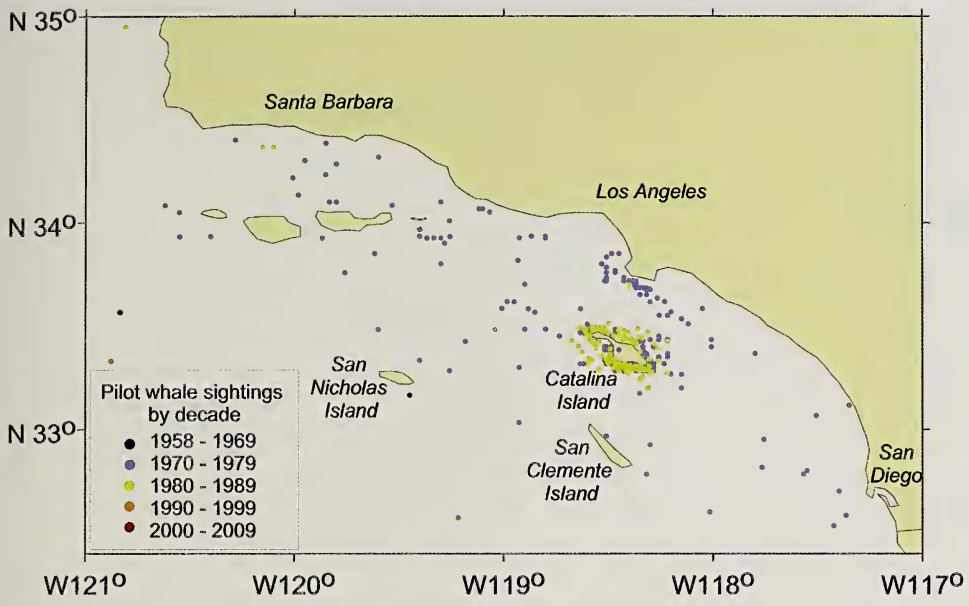

Fig. 3. Map of pilot whale sightings in the Southern California Bight, by decade.

land, especially in winter months, when squid spawn there. Dohl et al. (1981) tagged several individuals with spaghetti and ribbon tags, as well as one with a radio tag. Although relocations were limited, the radio tag data suggested that the animal remained within several tens of kilometers of Catalina Island for at least the one week of data collection. Detailed longitudinal studies of short-finned pilot whales in Hawaiian waters and elsewhere have shown that island-associated populations of this species do occur, and often have strong site fidelity to one or more islands, making them more susceptible to anthropogenic impacts such as those caused by military sonars (Mahaffy et al. 2015).

In spring through autumn months, sightings were more dispersed and were common in offshore waters (Norris and Prescott 1961; Leatherwood et al. 1973; Evans et al. 1984). The whales aggregated each winter, primarily off Catalina Island and the Palos Verdes Peninsula (Figs. 4 and 5). Norris and Prescott (1961) made 46 sightings between the Los Angeles area and Catalina Island in the late 1950s. Some identifiable individuals were seen repeatedly in the 1970s and 1980s (Walker 1975). Focal photo-identification work at Catalina Island (Shane and McSweeney 1990) showed that 32 photo-identified pilot whales were seen at least twice from 1980-1986, but work was cut short by a virtual disappearance of the whales after 1983 (see below). One 'resident' pod of 20 whales was always seen together and never with any other whales from Dec. 1984 to Feb. 1985. Pod stability was considered to be somewhere between the stable groups of killer whales (*Orcinus orca*) and the fission/fusion society of spinner dolphins (*Stenella longirostris*) (Shane and McSweeney 1990).

Although certainly not common, through the 1960s and 1970s, pilot whales were sometimes seen off central California (Brownell 1964; Barham 1982), northern California and Washington (Fiscus and Niggol 1965). There were also records for Oregon and British Columbia (Figs. 2 and 3). Pilot whale distribution in the eastern North Pacific potentially extended as far north as British Columbia (Ford 2014) and even southeast Alaska (Home

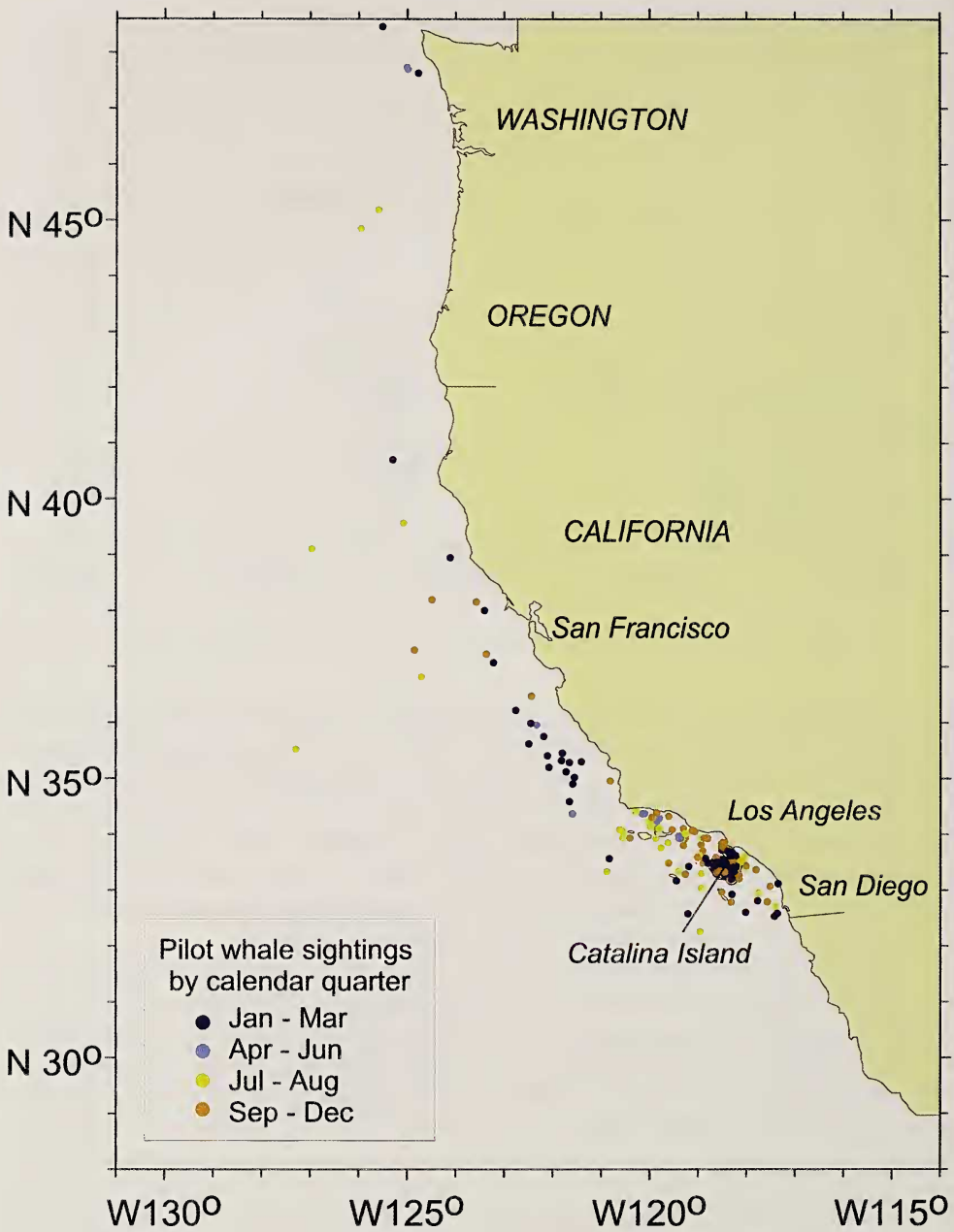

Fig. 4. Map of pilot whale sightings off the U.S. west coast, by season.

1980). In the latter area in 1977, small groups of pilot whales were reported consistently at the mouth of Glacier Bay and around Wrangell Narrows (Home 1980). Pilot whales have been absent from these areas in Alaska throughout the 1990s and 2000s (Dahlheim et al. 2009). Although survey effort has been much lower north of California, and so some of this is effort-related, it is evident that the majority of the animals off western North America

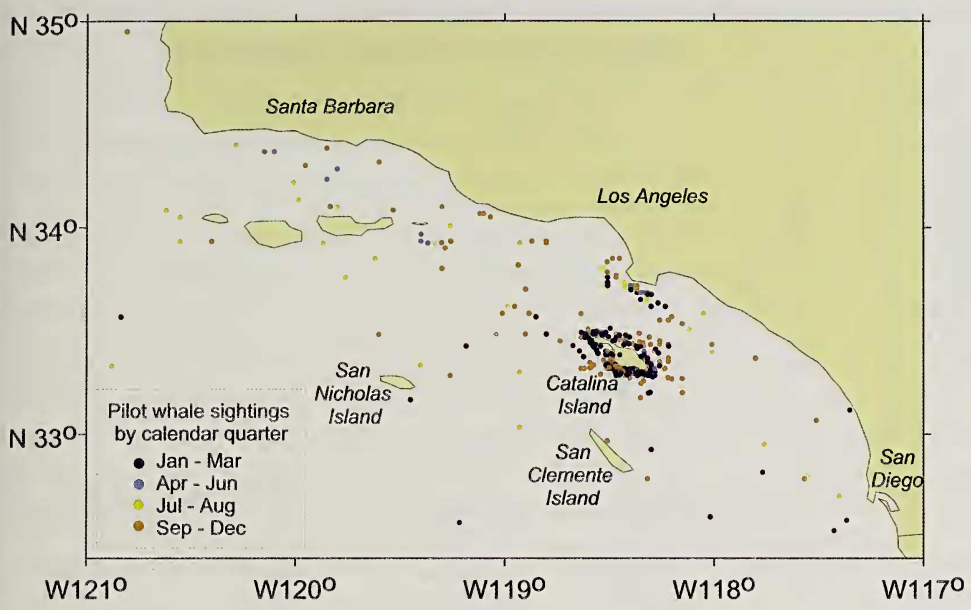

Fig. 5. Map of pilot whale sightings in the Southern California Bight, by season.

traditionally occurred off California. The regions from Oregon to the north were apparently areas of much lower density, with those areas north of the continental U.S. possibly visited only on an extralimital basis (Figs. 2-5).

The published literature contains no reliable, statistically-defensible estimates of historical population size for west coast pilot whales. However, some information can be gained from observations made by various workers in the 1970s and 1980s. On one day in April 1971, two groups estimated at 400 and 100 pilot whales were observed at Catalina Island, and another group of around of 40 was seen at San Clemente Island (Leatherwood et al. 1973). These authors suggested that total numbers probably peaked at over 1,000 whales. Surveys in the late 1970s by Dohl et al. (1981) suggested that the SCB 'resident population' was around 400 individuals, and winter influxes were thought to bring their numbers to about 2,000. However, it must be kept in mind that these were largely educated guesses, and not statistically-derived estimates.

Here we present the results of our new analysis of Catalina Island pilot whale abundance and density in Table 1 and Fig. 6. The results of the strip transect analyses suggest that previous "guesstimates" of the number of pilot whales at Catalina Island were reasonably accurate. For instance, Miller et al. (1983) estimated a maximum of 316 pilot whales at Catalina Island during the squid season in 1980-81. Our estimate for the initial survey in 1980/81 was of 300 individuals (density = 0.9744 animals/nm^2, CV = 0.50), which is very close to that of Miller et al's (1983). Despite high variances, there is strong evidence of a dramatic decline during the short study period of these surveys (Fig. 6, Table 1).

In winter 1983/84, the usual pilot whale aggregation at Catalina Island did not materialize, and this was coincident with the failure of market squid spawning that year, caused by a very strong El Niño event the previous year. Sea surface temperatures (SSTs) at Catalina Island were higher than normal in 1982/83 and 1983/84, then returned to normal

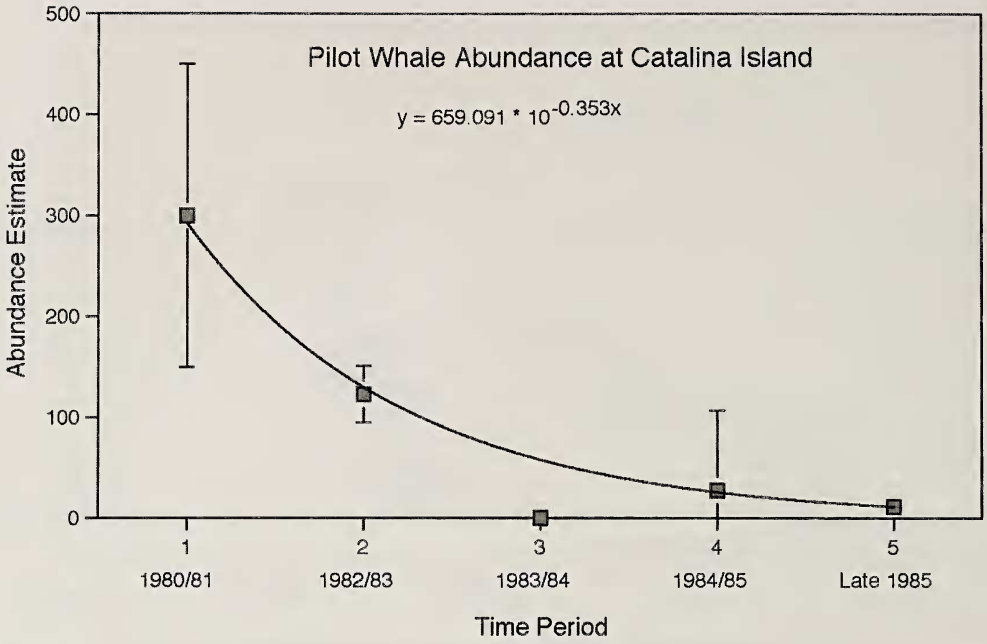

Fig. 6. Strip-transect estimates of abundance for pilot whales around Catalina Island, from CDFG and NMFS aerial surveys (Oliver and Jackson 1987).

in 1984/85[1]. Squid catch went from several thousand tons to just 16 tons, and catch per unit effort dropped dramatically in 1983 and 1984, returning to normal levels in 1985 (Zeidberg et al. 2006). Catch per unit effort was 10-22 tons/vessel day in years before and after, but dropped to near zero in 1983/4 (Zeidberg et al. 2006). The previous year (1982/83), pilot whales were only present from 12 January to 25 February, a very short season.

From 1980-1985, NMFS conducted surveys for pilot whales around Catalina Island. Pilot whales were seen on every flight around Catalina Island in 1980/81 (n = 15), and 1982/83 (n = 9). From December 1983- January 1984, and January 1985 eight flights were conducted, and no pilot whales were seen. Two groups were seen in 7 flights from 1984/85, and only a single group was seen in two flights in December 1985 (Oliver and Jackson 1987). Our strip transect analysis of these data shows a dramatic decline in estimated numbers of pilot whales at Catalina Island from 300 animals in 1980/81 to less than 50 from 1983-1985 (Fig. 6). Although the CVs for these estimates are fairly high (Table 1), the results show a pattern that is consistent with that noted by other researchers, and therefore can be considered somewhat reliable. Interestingly, the abundance estimates show some evidence of a drop in numbers already in 1982/83.

An hypothesis was advanced that pilot whales left Catalina Island in response to reduced squid spawning caused by the 1982/83 El Niño, and that Risso's dolphins came in to fill their niche (Shane 1991). According to this theory, the Risso's dolphins may have actively (aggressively), excluded the pilot whales from coming back (Shane 1991). Both species

[1] Shane, S. H. 1985. Detailed observations of a single pod of pilot whales and sightings of other marine mammals at Catalina Island, California in winter 1984-5. Unpublished report.

mainly feed nocturnally and rest diurnally at Catalina Island, and they both resided in the same areas where market squid were being caught (Shane 1995b). They are both primarily squid-eaters, so this may be an example of competitive displacement (Shane 1995a). Agonistic behaviors by Risso's dolphins toward pilot whales were observed on several occasions, suggesting that aggression was involved (Shane 1995a). If this is true, we do not know where the pilot whales went after leaving Catalina Island. It has been assumed that they moved away[1]. At least six of the pilot whales that were photo-identified off Catalina Island between 1983-1989 were matched to whales photographed across the San Pedro Channel, off the Palos Verdes Peninsula, between December 1986-January 1987 (Shane and McSweeney 1990; Kendall-Bar 2015; Kendall-Bar et al. 2016; ASJ unpubl. data); those group sizes generally varied from 20-30 whales, with perhaps as many as 50 on one day (ASJ unpubl. data). It is possible that pilot whales from the Catalina Island population may have relocated further south into Mexican waters; where there are fewer opportunities for photo captures. However, available photo-identification images taken since 1987 have not shown any matches to the Catalina Island individuals - including images taken off Mexico during ten encounters between 1996-2015 (Kendall-Bar 2015; Kendall-Bar et al. 2016; ASJ unpubl. data). Danil et al. (2010) noted a decrease in pilot whale strandings, associated with the decline in density of this species in the SCB. They suggested some evidence that pilot whales returned to California in later years, but not to the SCB.

Photo-identification and other data do not support the idea that the pilot whales moved north (Shane 1984; Kendall-Bar et al. 2016). Pilot whale records anywhere north of the U.S./Mexico border became rare after this, although a single group was seen offshore south of the San Francisco Bay area in 1991[2]. Five groups of pilot whales were observed on a NOAA survey of the Eastern Tropical Pacific in 1993 (Mangels and Gerrodette 1994). There were just eight published ship-based pilot whale sightings (with photo-IDs) north of Mexico (six in southern California, two in northern California) between 2007-2015; none were off Catalina Island (Kendall-Bar 2015; Kendall-Bar et al. 2016). Aerial surveys in the SCB (much of it around Catalina Island) from 2008-2013 covered 76,989 km and resulted in no pilot whale sightings (Jefferson et al. 2015), and only two pilot whale sightings were made on CalCOFI ship surveys in the SCB covering 25,079 km of effort from 2004-2008 (Douglas et al. 2014). Pilot whale numbers dramatically declined at Catalina Island following the 1982/1983 El Nino, and went from about 100 in 1983, to just a single pod being seen in most years after that, and in some years (1987, 1988, 1990, and 1991) none were seen (Shane 1994).

In the mid- to late-20th century, an extensive live capture fishery occurred to supply Marineland of the Pacific, Sea World, the U.S. Navy, and other institutions with pilot whales for captive display and research (Brown 1960; Norris and Prescott 1961; Walker 1975; Reeves and Leatherwood 1984; Forney 1994). Mortality during and soon after capture was high, and the capture process for this species was particularly difficult, requiring extended periods of time to approach schools to maneuver the hoop net into position for capture (Walker 1975). The captures were mostly from around the Palos Verdes Peninsula and the Channel Islands, so presumably the majority of these pilot whales were from the resident population, which would presumably have caused a great deal of disturbance and

[2] Jones, P. A., and I. D. Szczepaniak. 1992. Report on the seabird and marine mammal censuses conducted for the long-term management strategy (LTMS), August 1990 through November 1991, for the US Environmental Protection Agency. Unpublished report.

stress to the animals (see Walker 1975). Further exacerbating the negative effects of these captures, the majority of the captured animals were females. Of the 50 pilot whales captured between 1966 and 1982 in which sex was reported, 32 (64%) were females (Walker 1975; Reeves and Leatherwood 1984). Our compilation of records indicates that at least 76 individuals were removed from the area through live-captures between 1957 and 1982 (Table 3). Live-captures were especially common during the 1960s and 1970s (Fig. 7). These are known minimums, and since record-keeping was not always consistent (especially before 1972), true numbers were almost certainly higher.

Mortality of short-finned pilot whales in California fisheries is known from at least 1969 (Sinclair 1992). There has been little or no monitoring of most of these fisheries; except for a period of detailed study in the early 1980s (Miller et al. 1983) and recent observation of the swordfish driftnet fishery (Hanan et al. 1993; Carretta et al. 2017a), therefore much of the information comes from stranded specimens with forensic evidence of net entanglement on their bodies. Despite the confounding factor of increased monitoring after 1972 (with the enactment of the Marine Mammal Protection Act), mortality appears to have increased during the 1970s and 1980s (Fig. 7), with pilot whales known to have been killed in several types of encircling net fisheries (i.e., the squid purse seine and lampara net fisheries – together referred to as "round haul" fisheries) and driftnet fisheries (i.e., the California driftnet fishery and California/Oregon swordfish and shark driftnet fishery). Miller et al. (1983, p. 110) stated that the whales were sometimes "wrapped in the purse seine nets and cannot escape". When the net was retrieved by power block, often the tail of the whale would become entangled in the webbing, and the fishermen would cut the tail flukes off, allowing the whale to slip out. This would likely have been fatal to the whale in most cases. Less interaction was thought to have occurred with the dip net fisheries in the Catalina Island area (Miller et al. 1983). A popular account describing these fishery interactions near Catalina Island can be found in Eckert (1970).

In November 1977, at least eight pilot whales stranded in the Los Angeles area, showing some evidence of fishery interaction as a cause of death (Payne 1978). During the same time period, radio transmissions of squid fishermen were intercepted saying that several pilot whales had become entangled in nets and had to be 'beaten and cut' before they could be extracted (Payne 1978). This is suggestive of a serious fisheries interaction problem that had escaped the attention of both state and federal fisheries agents. A particularly damaging year appears to have been 1980, in which 12 pilot whales (a conservative figure) were known to be have been entangled in the squid purse seine fishery around Catalina Island (Miller et al. 1983), and seven pilot whales washed ashore in the Los Angeles area with evidence of fisheries interaction (Heyning et al. 1994). Although based on a small sample, in that year (1980) alone, it is estimated that as many as 60 pilot whales may have been killed as fisheries by-catch (DeMaster et al. 1985). Based on data obtained through a federally-funded marine mammal/fisheries interaction study (Miller et al. 1983), DeMaster et al. (1985) estimated that up to 30 pilot whales may have been taken in squid round haul nets and an additional 30 taken in driftnets. Combined with the 15 known strandings and three live-captures that year, up to 78 pilot whales may have been removed in 1980. If these were all or mostly from a small resident insular population of only a few hundred animals, then this would no doubt have had a catastrophic impact on the stock.

Total by-catch mortality appears to have varied quite a bit from year to year, but as we have shown, in some years it may have been substantial. The sampling of Miller et al. (1983) was limited, and it is very possible that 1980 was not an exceptional year but was more typical of a pattern that was occurring (largely unobserved) in the 1970s/80s. Although pilot

Table 3. Annual known removals of pilot whales from southern California. Note that these are known minimums and the true numbers removed are almost certainly higher.

Year	By-catches	Strandings	Live-captures	Unknown#	Total minimum removals
1952		3			3
1954		1			1
1956		1			1
1957		2	2		4
1958		1			1
1959		14	3		17
1960		3	4		7
1961		2			2
1962		15	1		16
1963		5			5
1965		1			1
1966	1		5		6
1967		1	6	1	8
1968			3		3
1969	1	1	8	1	11
1960s (date unknown)			9		9
1970			9		9
1971		28	2		30
1972		1	6		7
1973		6	1		7
1974			3		3
1975	2		4		6
1976		2	3		5
1977	5	4	0	1	10
1978		1	2		3
1980	19*	8	3		30
1982			2		2
1983	2	1	0		3
1985		2	0		2
1987		1	0		1
1988	1	1	0		2
1990	1	1	0		2
1992	1		0		1
1993	8		0		8
1994		1	0		1
1997	1		0		1
2003	1		0		1
2008		1	0		1
2014	2				2
TOTALS	**45**	**108**	**76**	**3**	**232**

* Miller et al. (1983) estimated that the true number could have been up to 36 animals. DeMaster et al. (1985) estimated that up to 60 pilot whales may have been taken as by-catch in 1980 from combined mortality in squid "round-haul" nets and oceanic gillnets.

Unknown here refers to the type of record (by-catch, stranding, or live capture).

whale population size and status in California was not known, a crude estimate (assuming a population of 300-400 pilot whales off Catalina Island – see Dohl et al. 1981 and Table 1) was that this may have represented 20-26% of the population, and this would certainly have been unsustainable.

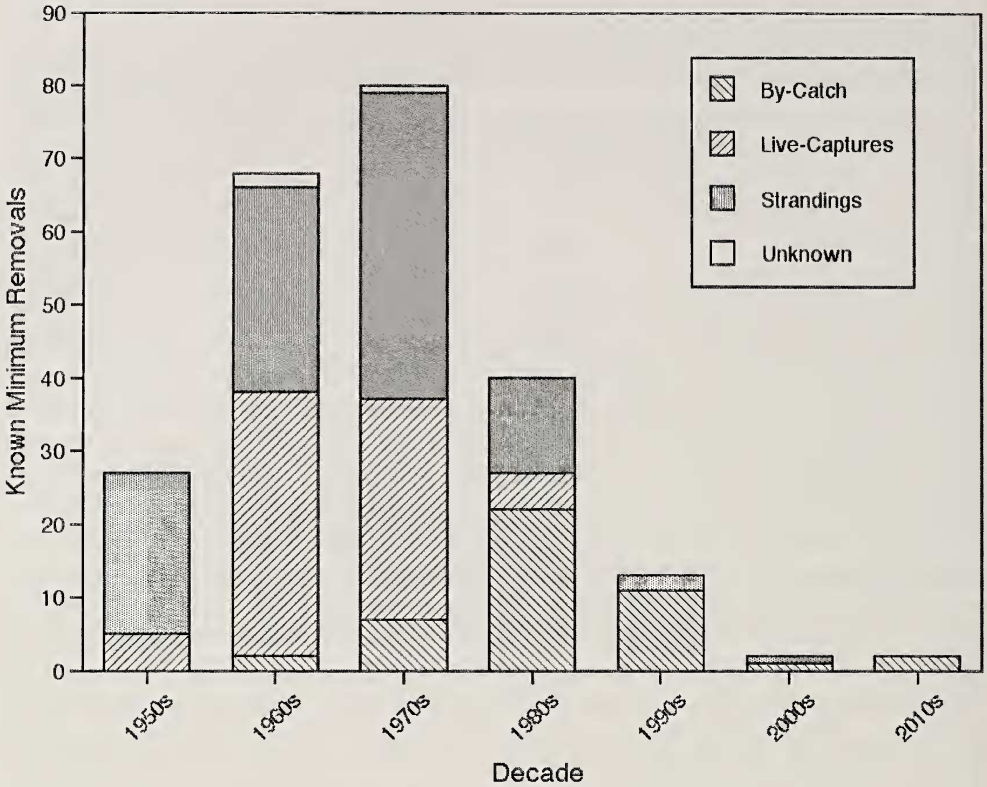

Fig. 7. Minimum levels of removal of pilot whales from southern California by decade. It is important to note that these are not estimates of total removals, which in many cases would likely be significantly higher.

Although occurring mostly outside of southern California (and thus possibly affecting a different, more far-ranging population), high pilot whale mortality in some years appears to have continued through the 1990s and early 2000s. Data from an onboard fisheries observer program suggested that estimated annual mortality of pilot whales in the California swordfish and shark driftnet fishery reached record-high levels of 20 animals in 1990, and 48 animals in 1993 (Lennert et al. 1994; Julian and Beeson 1998; Carretta et al. 2017b). A more recent and improved analysis of these data suggests that approximately 90 pilot whales were taken in the California drift gillnet fishery from 1990-2015 (Carretta et al. 2017b). This was during a time period in which fishing effort was somewhat lower and pingers were being used to reduce by-catch, therefore suggesting that by-catch in the 1980s and before may have been much higher (see Carretta et al. 2017b for details). Clearly, drift gillnet by-catch represents a significant portion of the overall fishery removals for California pilot whales, at least during the 1980s and 1990s. Some mortality also occurred in an experimental flying squid driftnet fishery off British Columbia from 1983-1987 (Jamieson and Heritage 1987, 1988). Based on a small sample of observed vessels, mortality was estimated at 37 pilot whales/year from 1980-1985 (Forney 1994).

Overall, our compilation of records indicates that at least 26 pilot whales were observed taken as by-catch between 1966 and 2014. However, including the animals that were considered to have been killed as by-catch from post-mortem examination, the total comes to

45 individuals, which is also likely an underestimate (Table 3). Observer coverage of these fisheries in the 1960s through 1980s was minimal. In addition, quite a few individuals depicted in the northeastern Pacific Pilot Whale Photo Identification Catalog (Kendall-Bar 2015) display deep and/or encircling scars on their dorsal fins that must have been caused by past entanglements, indicating that this is a serious threat.

Although there are no available estimates of how much mortality this may have caused, it is known that dip net and round haul fishermen regularly shot at pilot whales that drew their ire by coming close to their fishing operations, especially in the purse seine fisheries for squid (Miller et al. 1983). Some squid fishermen felt the pilot whales' presence could be beneficial, but most tended to regard pilot whales as competitors for squid. An acoustic harassment device was tried in early 1982, with apparently no response by the whales (Miller et al. 1983).

In November 1977, coastal residents near Malibu and Point Dume reported hearing shots and explosions (note – the explosions may have been seal bombs, which are known to have been used on marine mammals by fishermen trying to protect their catch and their gear) during the night, at a time when about 400 pilot whales had been reported off the coast (Payne 1978). In December 1980, during the fishery study by Miller et al. (1983), pilot whales were observed near the lights of fishing boats on 35% of the 15-minute observation periods. Miller et al. (1983) stated that "heavy gunfire was noted during December with 156 shots recorded during 15.2 hours of observations" (Miller et al. 1983, p. 108). These represent just two examples of what might have been a common practice at the time.

Although Shane (1994) felt that the shooting was mainly directed at California sea lions (*Zalophus californianus*), it must be assumed that this shooting caused some additional level of mortality for pilot whales, and because the interactions typically occurred at night, they may have easily gone un-noticed. Fishermen claimed that pilot whales sometimes scared the squid away from their nets and even damaged fishing gear, and thus some fishermen had negative feelings toward the whales. Eckert (1970) provided a popular account of the situation around Catalina Island, including a description of the live capture of one animal that died soon afterwards, apparently from having been shot in the head with a 0.38 caliber bullet in an earlier incident.

Conclusions

Despite quite a bit of uncertainty, southern California short-finned pilot whales may have represented a small, vulnerable population associated with the Channel Islands. Strandings have been incompletely documented, but we do know that just three mass strandings occurring in 1959, 1971, and 1980 resulted in the removal of 49 pilot whales from the Channel Islands area. While most strandings are thought to result from natural causes, the area around the southern California Channel Islands is adjacent to a major U.S. Naval base in San Diego, and the possibility that at least some of these strandings were associated with naval sonar must be considered. Both species of pilot whales are prone to mass stranding (Sergeant 1982). A number of mass strandings of deep-diving odontocete cetaceans have been linked to the use of modern low- and mid-frequency active sonar (e.g., Balcomb and Claridge 2001; Southall et al. 2006), which was developed in the 1950s and has been in common use by the Navy in southern California waters for many decades (d'Amico and Pittenger 2009). Pilot whales (*Globicephala* spp.) have been among the species implicated as victims of this technology (Parsons et al. 2008).

Losses from these occasional mass strandings and certain anthropogenic causes (fisheries by-catches, shootings by fishermen, and live captures for aquarium display) may have been affecting the viability of the pilot whale stock since before the MMPA took effect in 1972/73. Although the estimated by-catch for the drift gillnet fishery was approximately 90 individuals between 1990 and 2015 (Carretta et al. 2017b), levels of anthropogenic mortality appear to have reached into the dozens of animals in at least some of the earlier years, and were apparently quite high throughout the 1960s to 1980s (Fig. 7). This could have had a catastrophic effect on a small island-associated population of just a few hundred pilot whales (as has been proposed). We do believe that the 1982/83 El Niño event played a role in their disappearance, but we also think that it was not the only (or even major) factor involved.

Pilot whale sightings off the U.S. west coast have increased recently, some part of this increase is likely due to increases in sighting effort and whalewatching trips in recent years. It is unknown whether these animals are part of a wider-ranging pilot whale population, or if they may represent some individuals from the population that previously was associated with Catalina Island. No photo-ID matches have been made since 1987 to any of the seasonally-resident pilot whales that had been identified off Catalina Island (Kendall-Bar 2015; Kendall-Bar et al. 2016; ASJ unpubl. data). Sightings of pilot whales are still quite rare in the SCB, with no sightings reported off Catalina Island. Squid catches have recovered, and Risso's dolphins (another squid specialist) are still commonly sighted around this island (Jefferson et al. 2015).

If the pilot whales from around Catalina Island represented an extirpated island-associated population, this could explain why pilot whales have not returned to Catalina Island during the past three decades, despite increased regulation of fisheries and low recent levels of documented pilot whale by-catch in all fisheries combined. It is also possible that any surviving pilot whales from this population may have relocated further south into Mexican waters; however, no matches have been made from the available photos taken off Mexico. We therefore conclude that the disappearance of short-finned pilot whales from southern California in the early 1980s was almost certainly caused in part by the mortality of dozens of animals from fisheries by-catches and live-captures, in combination with additional removals from shootings by fishermen (with occasional mass strandings, some possibly anthropogenic, also contributing). If there was indeed a resident island-associated population of short-finned pilot whales in southern California, it might even have been extirpated by these unregulated removals. However, it is possible that another group (or groups) of pilot whales could begin to take up residence in the Catalina Island area, taking advantage of the squid resource, and future research should be directed towards monitoring this possibility.

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